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Results of the 1984 NASA/JPL Balloon Flight Solar Cell Calibration Program

R.G. Downing R.S. Weiss

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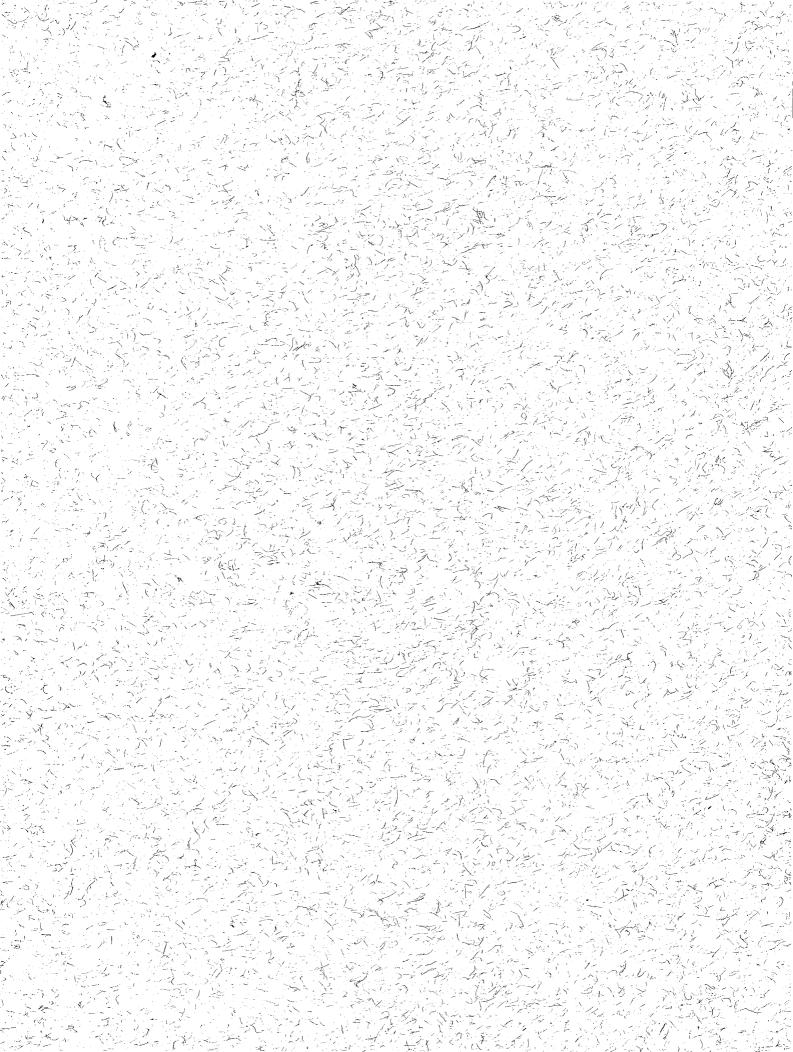
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National Aeronautics and Space Administration

Jet Propulsion Laboratory California Institute of Technology Pasadena, California



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ABSTRACT

The 1984 solar cell calibration balloon flight was successfully completed on July 19, meeting all objectives of the program. Thirty-six modules were carried to an altitude of 36.0 kilometers. The calibrated cells can now be used as reference standards in simulator testing of cells and arrays.

ACKNOWLEDGMENT

The authors wish to extend appreciation for the cooperation and support provided by the entire staff of the National Scientific Balloon Facility located in Palestine, Texas. Gratitude is also extended to assisting JPL personnel, especially B.E. Anspaugh, for providing cell spectral response information and data reduction assistance. The cooperation and patience extended by all participating organizations are greatly appreciated.

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I. INTRODUCTION

The primary source of electrical power for unmanned space vehicles is the direct conversion of solar energy through the use of solar cells. As advancing cell technology continues to modify the spectral response of solar cells to utilize more of the sun's spectrum, designers of solar arrays must have information detailing the impact of these modifications on cell conversion efficiency to be able to confidently minimize the active cell area required and, hence, the mass of the array structure.

Since laboratory simulation of extra-atmospheric solar radiation has not been accomplished on a practical scale with sufficient fidelity, high altitude exposure must be taken as the best representation of space itself. While a theoretical prediction (Reference 1) and experimental evidence have suggested that an altitude greater than 30 kilometers is sufficient to give space-equivalent calibration, the final decision as to an adequate altitude must await the results of the space shuttle solar cell calibration experiment flown in August 1984.

To reach and maintain the chosen altitude of 36 kilometers, the calibration program makes use of balloons provided and launched by the National Scientific Balloon Facility of Palestine, Texas.

II. PROCEDURE

To insure electrical and mechanical compatibility with other components of the flight system, the cells are mounted by the participants on JPL-supplied standard modules according to directions in Reference 2, which details materials, techniques, and workmanship standards for assembly. The JPL standard module is a machined copper block 3.7 cm x 4.8 cm x 0.3 cm thick, rimmed by 0.3 cm thick fiberglass, painted a high reflectance white, with insulated solder posts and is permanently provided with a precision (0.1 percent, 20 ppm/°C) load resistor appropriate for scaling the cell output to the telemetry constraints. This load resistor, 0.5 ohm for a 2 cm x 2 cm cell, for example, also loads the cell in its short circuit current condition.

The mounted cells are then subjected to preflight measurements in the JPL X25L solar simulator. These measurements, when compared to postflight measurements under the same conditions, may be used to detect cell damage or instabilities. Prior to shipment to the launch facility, the modules are mounted on the sun tracker bed plate (Figure 1). Upon arrival at the Palestine facility, the tracker and module payload are checked for proper operation, and the data acquisition and Pulse Code Modulation telemetry systems are calibrated. Mounting of the assembly onto the balloon is then accomplished (Figure 2).

At operating altitude the sun tracker bed plate is held pointed at the sun to within \pm 1 deg. The response of each module, temperatures of representative modules, sun lock information, and system calibration voltages are sampled twice each second and telemetered to the ground station, where they are presented in teletype form for real-time assessment and are also recorded on magnetic tape

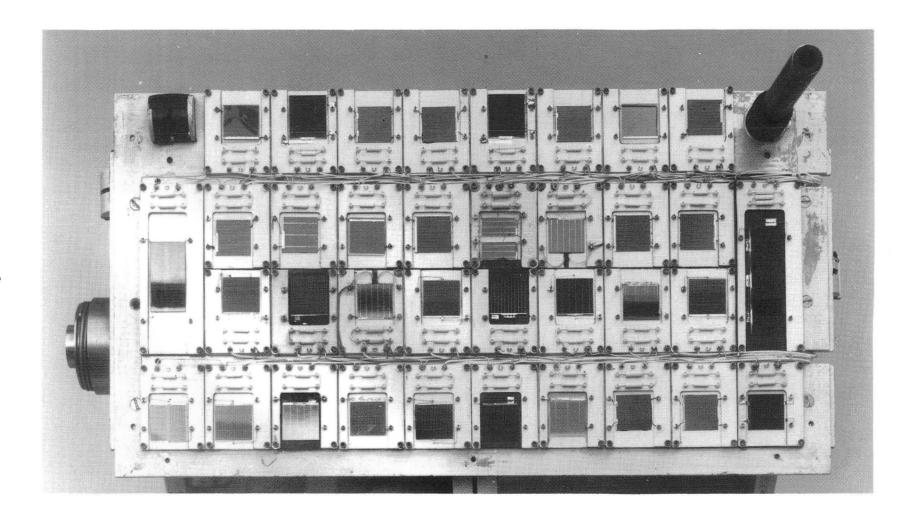


Figure 1. 1984 solar module payload

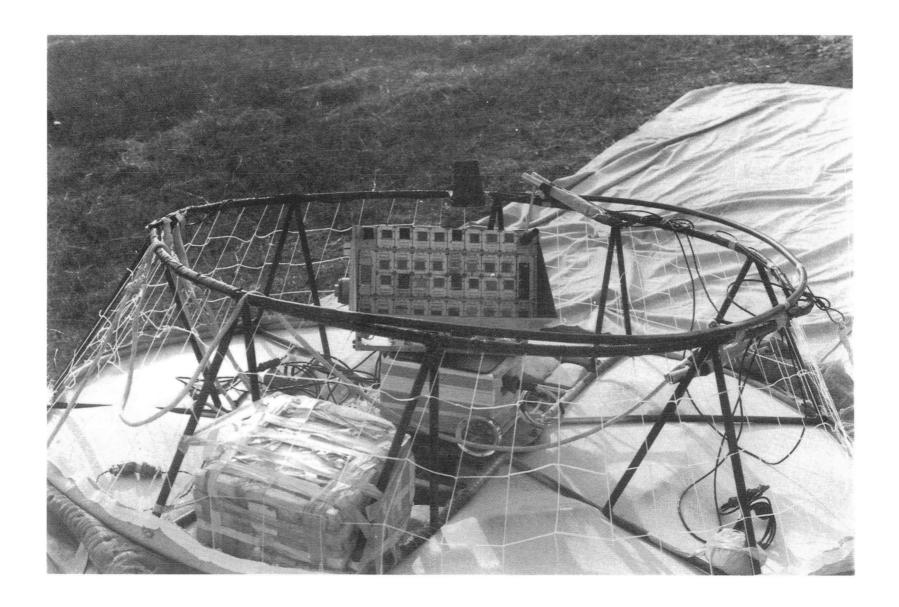


Figure 2. Balloon mount

for later processing. Float altitude information is obtained from data supplied by the balloon facility. A plot of altitude in kilometers versus Central Daylight Time for the 1984 flight is shown in Figure 3.

III. SYSTEM DESCRIPTION

A solar tracker mounted in a frame on top of the balloon carries the module payload, while the transmitter of the data link is located in the lower gondola along with batteries for power and ballast for balloon control. At completion of the experiment, the upper payload and lower gondola are returned by parachutes and recovered. A more complete description of the system, including the sun tracker, can be found in Reference 3.

IV. DATA REDUCTION

The raw data as taken from the magnetic tape is corrected for temperature and sun-earth distance according to the formula (Reference 4):

$$V_{28,1} = V_{T,R}(R^2) - \alpha(T-28)$$

where

 $V_{T,R}$ = measured module output voltage at temperature T and distance R.

R = sun-earth distance in astronomical units.

 α = module output temperature coefficient (supplied by participants).

T = module temperature in °C.

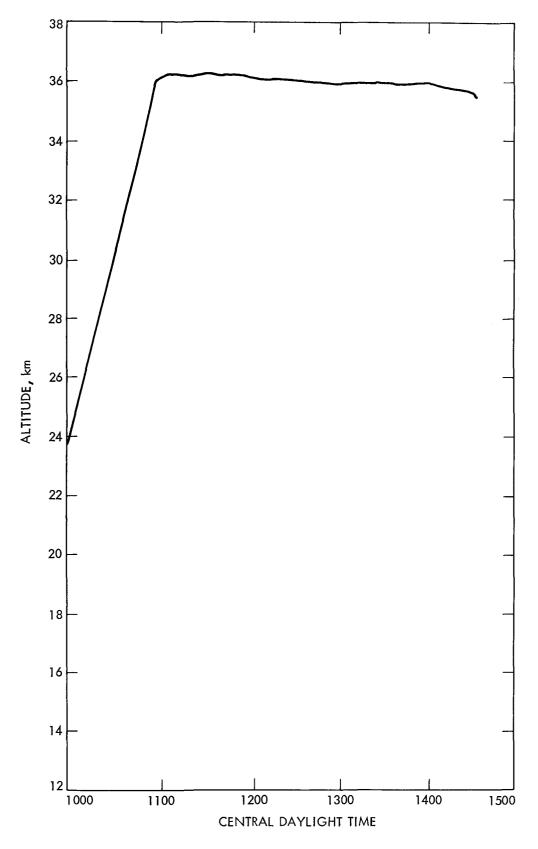


Figure 3. Flight 1984 altitude versus time

The calibration value is taken to be the average of 200 data points taken around the time of solar noon after indicated temperature stability.

The flight data were thus reduced, and modules with their data and calibration values were returned to the participants. This information is collected in Table 1. The placement of modules on the field of the tracker bed for the 1984 flight is shown in Figure 4.

A detailed discussion of data reduction and an analysis of system error may be found in Reference 3. The error in the calibration values due to radiation absorption and scattering by the residual atmosphere at float altitude is estimated to be less than 0.2 percent (Reference 1).

V. MONITOR CELLS

Several standard modules have been flown repeatedly over the 22-year period of calibration flights. The record of the one with the longest history, BFS-17A, appears in Table 2. This data shows a standard deviation of 0.23 percent and a maximum deviation of 0.58 percent from the mean.

In addition, the uniformity of the solar irradiance (i.e., no spurious reflections, shadowing) over the field of the modules has been demonstrated since the location of this module was changed in that field from flight to flight.

Table 1. Cell Calibration Data

1	CHANNEL NUMBER	MODULE NUMBER	ORGANIZATION CODE	TEMP. INTENSITY AVERAGE	STANDARD DEVIATION	AMO, SOI 1 AU, 28 PRE-FLT	_AR SIM. 3 DEG.C POS-FLT	٧s.	& FLT FLIGHT VS. PRE-FLT	TEMP. COEFF. (MV/°C)	COMMENTS
2	1	84-170	SOLAVOLT	67.70	-06573	68,60	67.10	-2-19	-1.31	.071	
3											K7
4 84-002 JPL 59.61 .06414 59.60 59.70 .17 .02 .038 GA-AS 5 84-117 COMSAT 71.59 .07372 71.10 69.60 -2.11 .68 .033 K7 6 84-103 ASEC 61.29 .06663 60.90 60.90 .00 .65 .041 GA-AS 7 84-172 SOLAVOLT 77.23 .05969 76.60 76.30 .39 .82 .039 8 84-160 TRW 86.55 .08185 85.80 85.4047 .87 .033 9 84-110 ASEC 61.09 .06441 61.00 60.80 .33 .15 .036 GA-AS 10 84-161 TRW 86.65 .06466 85.80 85.4047 .87 .033 .15 .036 GA-AS 11 84-106 ASEC 85.17 .07306 85.10 84.8035 .08 .061 12 84-175 SOLAVOLT 67.23 .07874 66.00 65.8035 .08 .061 12 84-175 SOLAVOLT 67.23 .07874 66.00 65.8035 .08 .061 14 8FS-17A JPL 59.84 .07064 60.01 60.60 .8343 .036 REF STD 15 73-182 JPL 67.62 .05880 68.00 68.50 .7455 .055 TEMP MONITOR 16 84-120 ASEC 80.29 .07308 80.00 79.70 .38 .02 .061 17 84-104 GE 58.63 .05918 58.90 58.90 .00 .0046 .040 GA-AS 18 84-138 HUGHES 76.94 .05855 76.00 75.8026 1.24 .020 19 84-182 SPECTROLAB 92.04 .04885 90.20 89.7055 2.03 .036 XSAT 20 78-110 HUGHES 95.59 .06606 93.40 93.40 93.40 .00 2.35 .039 K7 21 73-183 JPL 66.71 .07159 67.30 67.80 .74 .88 .055 TEMP MONITOR 22 84-122 GE 85.13 .06610 84.50 84.40 .02 .25 .039 K7 21 73-183 SPECTROLAB 97.47 .07244 95.90 95.50 .42 1.64 .038 16 24 84-183 SPECTROLAB 85.04 .08068 84.40 84.00 .47 .76 .041 DSCS 23 83-120 HUGHES 97.47 .07244 95.90 95.50 .42 1.64 .038 16 25 84-184 SPECTROLAB 85.04 .08068 84.40 84.00 .47 .76 .041 DSCS 28 84-183 SPECTROLAB 85.04 .08068 84.40 84.00 .47 .76 .041 DSCS 28 84-184 SPECTROLAB 85.04 .08068 84.40 84.00 .47 .76 .041 DSCS 28 84-184 SPECTROLAB 83.04 .08068 84.40 84.0047 .76 .041 DSCS 28 84-184 SPECTROLAB 89.0 .06523 87.60 85.50 .36 .1.14 .68 .042 K6 38 84-184 SPECTROLAB 89.0 .06523 87.60 86.60 .1.14 .68 .042 K6 38 84-185 SPECTROLAB 89.0 .06523 87.60 86.60 .1.14 .68 .042 K6 38 84-184 SPECTROLAB 89.0 .06523 87.60 86.60 .1.14 .68 .042 K6 38 84-185 SPECTROLAB 89.0 .06523 87.60 86.60 .1.14 .68 .042 K6 38 84-184 SPECTROLAB 89.0 .06523 87.60 86.60 .1.14 .68 .042 K6 38 84-184 SPECTROLAB 89.0 .06	3										
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Table 2. Repeatability of Standard Solar Cell BFS-17A (36 flights over a 22-year period)

Flight Date	Output, mW	Flight Date	Output, mb
9/5/63	60.07	4/5/74	60.37
8/3/64	60.43	4/23/74	60.37
8/8/64	60.17	5/8/74	60.36
7/28/65	59.90	10/12/74	60.80
8/9/65	59.90	10/24/74	60.56
8/13/65	59.93	6/6/75	60.20
7/29/65	60.67	6/27/75	60.21
8/4/66	60.25	6/10/77	60.35
8/12/66	60.15	8/11/77	60.46
8/26/66	60.02	7/20/78	60.49
7/14/67	60.06	8/8/79	60.14
7/25/67	60.02	7/24/80	60.05
8/4/67	59.83	7/25/81	60.07
8/10/67	60.02	7/21/82	59.86
7/19/68	60.31	7/12/83	60.10
7/29/68	60.20	7/19/84	59.84
8/26/69	60.37	• •	
9/8/69	60.17	Mean	60.21
7/28/70	60.42	Std. Deviation	0.24
8/5/70	60.32	Maximum Deviation	0.59

Each data point is an average of 20 to 30 points per flight for period 9/5/63 to 8/5/70.

For flights on 4/5/74 through 7/1/75 each data point is an average of 100 or more flight data points.

For flights starting in September 1975, each data point is an average of $200\ \text{data}$ points.

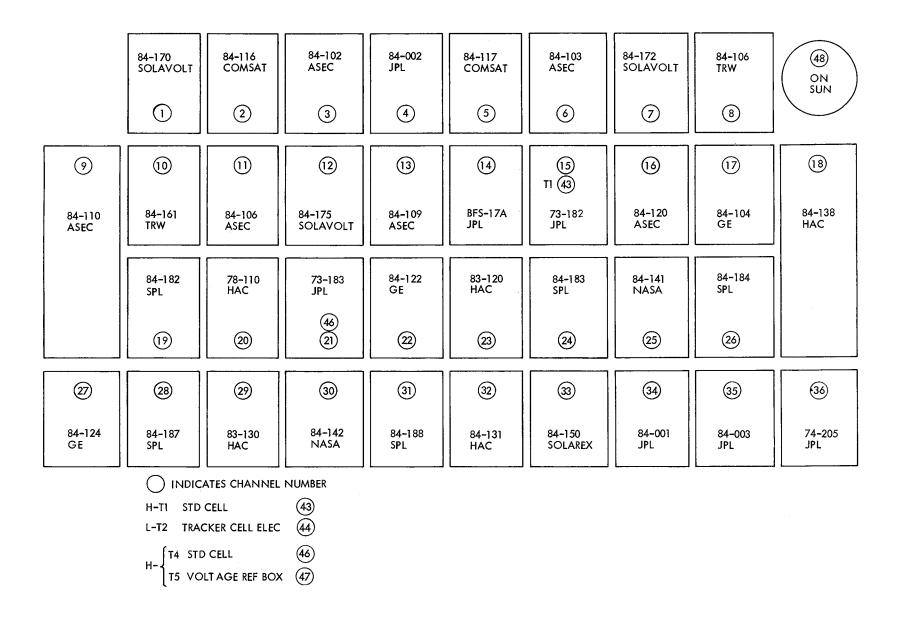


Figure 4. 1984 module location chart

VI. CONCLUSIONS

As emphasized by the history of repeatability of cell BFS-17A, viz, \pm 1% (see Table 2), silicon cells, when properly cared for, are stable for long periods of time and may be used as standards with confidence.

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